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THE NEWARK SYSTEM OF NEW JERSEY.[1]

THE Newark system extends across the northern part of New Jersey, forming a belt which is about thirty-two miles wide along the Delaware River, while its width at the New York state line is about fifteen miles. The southeastern boundary from Trenton northeastward to Staten Island is for the most part formed by the overlying Cretaceous beds. Near Trenton, however, the underlying Philadelphia gneiss outcrops for a few miles. The waters of the Kill von Kull, New York Bay and Hudson River form the boundary from Staten Island northward. The northwestern boundary is irregular and is formed entirely by older rocks, — crystallines and Palæozoic shales and limestones. This paper has to do with that part of the area lying southwest of a line drawn from Metuchen, through Plainfield to Peapack.

Topography.—In general the area is a gently rolling plain, having an average elevation of 100 to 250 feet A. T. The plain is interrupted by the valleys and trenches of the present streams and hills, ridges and plateaus of harder rock. The largest of these is the Hunterdon plateau. Commencing at Raven Rock on the Delaware River a prominent escarpment extends northeastward, past Flemington, where it bends north and then northwest, finally terminating near Lansdown about eighteen miles from the

[1] Published by permission of the State Geologist of New Jersey. For a more detailed statement of all the facts upon which this paper is based, see Annual Report of the State Geologist for 1896, pp. 25–88.

Delaware River. Northwest of this line is a broad plateau, having an average elevation of about 600 feet. It extends westward into Pennsylvania, being dissected by the Delaware to a depth of 400 to 500 feet. Its highest part is along the south and east, about a mile back from the top of the escarpment. Thence it declines in elevation very gently northward and westward. The escarpment is most marked in the vicinity of Flemington, where the contrast in hardness between the rocks of the plateau and of the low ground is the most marked.

Sourland plateau extends from Lambertville on the Delaware, northeastward for seventeen miles. It has an average width of four and a half miles and varies in height from 450 to 560 feet. The backbone of the plateau is a belt of trap rock, a mile in width, but the hard sandstones and argillites on either side rise nearly to the same elevation. In the vicinity of Hopewell and northward, the plateau is separated from the low plain to the southeast by an escarpment varying from 200 to 400 feet in height. Other masses of trap rock forming minor hills and ridges rise from 200 to 500 or 600 feet above the general level. Along the northwestern boundary also there are several marked elevations due to massive quartzite conglomerates.

THE ROCKS.

It has been found possible to divide the sedimentary rocks of the Newark system into three subdivisions.[1] These are not based upon palæontological evidence, since fossils are too few to be used for this purpose, but on lithological differences, which permit the establishment of recognizable horizons. While fully aware of the dangers attending the use of lithological characters in correlation, the author is confident that in this case they have been reduced to a minimum, owing to the care with which the beds have been traced step by step. The beds of the three series

[1] Practically all the outcrops and sections — many hundreds in number — have been examined and plotted. All the roads and nearly all the stream beds have been traversed. So monotonous are the beds that it is only by this detailed work that there is any possibility of detecting and tracing the structural complications.

grade into each other vertically through transition zones several hundred feet in thickness, so that it is not always easy to delimit them exactly in the field. Moreover, all three members lose to a great extent their distinctive characteristics when traced along the strike of the northwestern boundary north of Pittstown. With these exceptions, however, the beds of each division are *en masse* quite unlike and readily separable from each other. The accompanying map shows their location and the main faults by which they are repeated.

Stockton series.—The basal beds of the system are found at Trenton where they rest unconformably upon the older crystalline rocks. They consist of (*a*) coarse, more or less disintegrated arkose conglomerates; (*b*) yellow, micaceous, feldspathic sandstone; (*c*) brown-red sandstones or freestones, and (*d*) soft red argillaceous shales. These are interbedded and many times repeated, a fact which indicates rapidly changing and recurrent conditions of sedimentation. Although there are many layers of red shale in this subdivision the characteristic beds are the arkose conglomerates and sandstones, the latter of which afford valuable building stones.

In addition to the cross-bedded structure which often prevails in the sandstones, ripple-marks, mud-cracks and impressions of rain drops occur. The rapid alternation from conglomerates to shales and *vice versa*, the changes in composition in individual beds, the cross-bedding, ripple-marks, etc., all indicate very clearly that these beds were deposited in shallow water in close proximity to the shore. The bulk of the material of which they are composed was derived from the crystalline rocks on the south and southwest.

Owing to the tilting and faulting, the Stockton beds outcrop in several belts as shown by the map. The most important areas are (*a*) the Trenton area, which extends northeastward to Princeton beyond which place it is mostly buried by Cretaceous and Jamesburg deposits; (*b*) the Hopewell area along the southeastern face of the Sourland plateau, where the upper part of the series has been brought to the surface by a fault; (*c*) the

Stockton area, where the upper layers are exposed in numerous quarries near the village of Stockton; (*d*) the area north of Flemington.

In the Stockton area the upper limit of the series extends along the crest of the escarpment of the Hunterdon plateau, the steep slope being formed by the upper beds of Stockton series which are here predominantly red shales, with an occasional sandy layer. Northeastward this belt is terminated by a great fault which crosses the beds obliquely so that the belt becomes narrower and finally pinches out a few miles southwest of Flemington. Within this area the more massive conglomeratic beds form three broad low ridges, each of which terminates somewhat abruptly at the fault.

An important modification was found in the character of this series within the area north of Flemington. Where the rocks first occur near Flemington, they consist of coarse arkose sandstones and red shales. The transition here to the overlying series is through sandy shales similar in texture and thickness to the uppermost layers northwest of Stockton. As the northwestern border of the formation is approached the arkose conglomerate and sandstones give place to red shale beds or sandstones and conglomerates of a different type. For a distance of four miles southeast of Clinton the basal beds of the formation rest unconformably upon Silurian shales, limestones, and still older quartzite and gneiss. Material from these formations has determined the local character of the Newark beds. In place of the free-splitting brown and red sandstones, there occur coarser beds made up largely of thin bits of shale, and small quartzite pebbles. Although the Stockton beds rest in part upon the limestone and gneiss, these rocks occur but rarely in this part of the newer formation. Their comparative absence has not been satisfactorily explained.

Lockatong series.—Above the Stockton beds there is a series of hard, dark-colored shales and flagstones, which I have called the Lockatong beds from the name of the creek in Hunterdon county, along which they are best exposed. They consist of

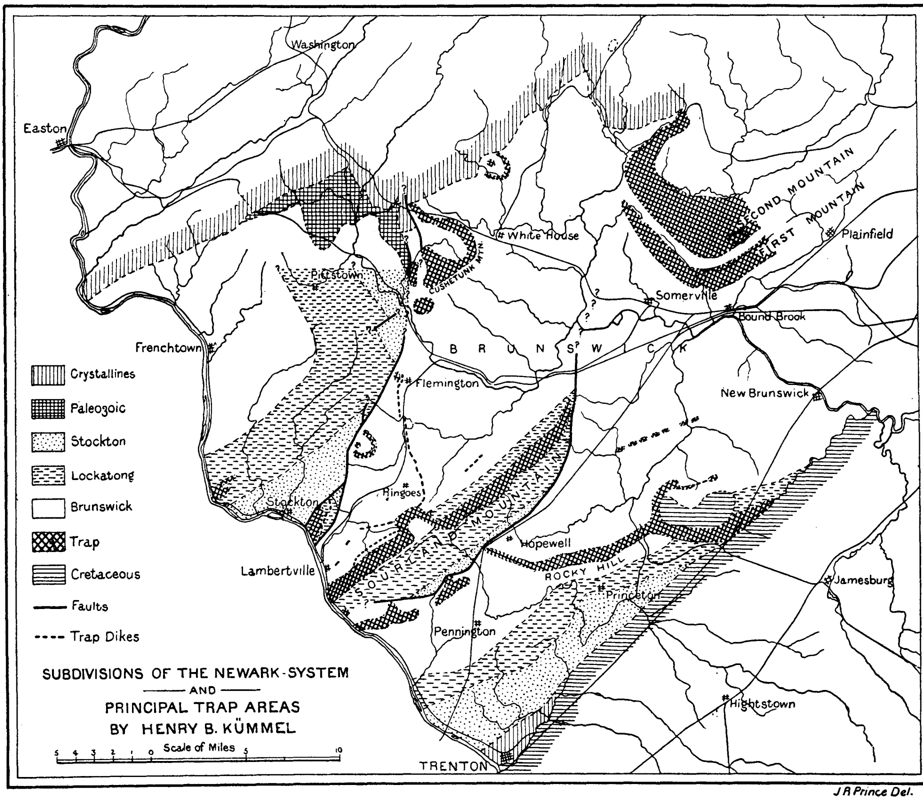
(*a*) carbonaceous shales, which split readily along the bedding planes into thin laminæ, but have no true slaty cleavage; (*b*) hard, massive, black and bluish-purple argillites; (*c*) dark gray and green flagstones; (*d*) dark red shales approaching a flagstone; (*e*) and occasional thin layers of highly calcareous shales. There are all gradations between these somewhat distinct types, so that the varieties of individual beds are almost countless. Some of the argillites are specked with minute crystals of calcite and the faces of joint planes and cavities are frequently covered with deposits of the same mineral. Minute crystals of iron pyrites occur frequently in some layers, but apart from them and the calcite, secondary minerals were not found, macroscopically, in these beds.

Both ripple-marks and mud-cracks occur at all horizons in the Lockatong beds, showing that shallow water conditions prevailed throughout the time of their deposition. On the other hand, the absence of strong currents or violent shore action is indicated by the extreme fineness of the material.

Owing to the faulting these beds occur in several well-marked belts, in each case overlying conformably the Stockton series. The first belt reaches the Delaware between Wilburtha and Washington's Crossing, and extends northeastward through Ewingville, Lawrenceville, and Princeton, where there are several large quarries in the argillite beds. East of the Millstone River the limits of this belt cannot be determined accurately owing to the veneer of the Jamesburg formation, but from a few scattered outcrops and borings, these beds probably cross the Raritan River below the mouth of Lawrence Brook.

The Lockatong beds occur again along the southeastern side of the Sourland plateau, resting upon the narrow belt of Stockton sandstones which forms the escarpment of this upland. From the Delaware River to the village of Newmarket the upper limit of the beds lies a little below the trap sheet which forms the backbone of the upland. The interval between them is occupied by the softer red shales of the third series, which are somewhat metamorphosed near the igneous rock. Northeast of New-

market, owing to a sharp curve in the trap sheet by which it crosses the beds nearly at right angles, the Lockatong beds occur on both sides of the trap, their upper limit being about 1760



feet above the latter. The plateau, which owes its elevation to the hardness and durability of the argillite flagstones and trap, is terminated on the northeast by the fault.

The most extended outcrop of the Lockatong beds occurs on the Hunterdon plateau, in the region known as "the Swamp." As shown on the accompanying map the width of the outcrop is greater here than elsewhere due to diminished dips, 10° to 13° here as against 15° to 20° on the Sourland plateau, and the belt

forms a broad regular curve, due to the synclinal structure. The height of the Hunterdon plateau is due to the wide outcrop, curving strike and hardness of these rocks and of the upper layers of the Stockton series, all of which have retarded greatly the forces of denudation, so that whereas the adjoining softer rocks have been reduced to an average elevation of under 200 feet, this belt has an elevation of from 500 to 700 feet.

Along the Lockatong and Wickecheoke creeks, which have deeply incised the margin of the plateau, rapids and falls abound. Hard dark red flags are interbedded with the black argillites, and some of the more pronounced beds can be easily traced for several miles along the curving strike. This was done in so many cases at different horizons as to render it almost certain that this belt is not traversed by faults of any magnitude. The width of outcrop is due to the great thickness and the gentle dip.

Modification of the Lockatong beds.—Important modifications were found to occur in this series near the northwestern boundary. The shales and argillites grade into sandstones, and these into coarse conglomerates. Some layers become slightly arkose. This change occurs *along the strike*, and is accomplished within six miles or less. Within a mile and one-half along the strike from the point where the first pebble-bearing layers were noted, the series is composed chiefly of massive conglomerates in which the pebbles are frequently six or eight inches in diameter. Since not only the Lockatong beds but the next higher series also grade into these marginal conglomerates, it will be well to postpone further consideration of them for a brief space.

The Lockatong beds give rise to a rather heavy wet clay soil. The surface is quite thickly strewn with slabs of argillite and flagstone, and on the slopes outcrops are generally abundant. Except in places favorable to the accumulation of the soil from higher slopes its depth is generally less than five or six feet.

The Brunswick shale series.—I have applied this name to the great thickness of soft shales and occasional sandstone layers

which overlie the Lockatong beds, and which are so well exposed in the valley of Raritan, particularly near New Brunswick. They are predominantly red in color, although a few purple, green, yellow, and black layers occur. In general this series consists of a monotonous succession of very soft argillaceous red shales which crumble readily to minute fragments, or split into thin flakes. Much of it is porous, the minute, irregular-shaped cavities being often partially filled with a calcareous powder. Calcite veins and crystals are common in some layers. Locally lenticular masses of green shale occur in the red. In size these range up to a foot or two in diameter, and vary in shape from nearly spherical to lenticular masses, narrowing down to thin sheets along cracks. They are undoubtedly due to chemical changes resulting in the leaching of the shale.

Although the majority of this series are soft red shales, there are some hard layers, chiefly near the base, and occasional beds of fine-grained sandstone and flagstones, some of which afford valuable building material. Massive conglomerates along the northwestern border are in part the shoreward correlatives of the red shales.

Evidence that the shales were deposited in shallow water is abundant. Ripple-marks, mud-cracks and rain-drop impressions occur at many horizons. In some quarries imprints of leaves, of tree stems, or the stems themselves are frequently found. The numerous reptile tracks which have made the Newark beds famous occur chiefly in this subdivision. Typical exposures occur along the Raritan River, particularly near New Brunswick.

The Brunswick beds underlie all the region under discussion except that occupied by the Lockatong and Stockton beds and the trap rocks. This area is considerably more than two-thirds of the whole, partly because of the great thickness of the series and partly because the beds have been bent into broad, gentle folds. Standing on the northern end of Sourland plateau one has a magnificent view of the low plain formed on the Brunswick shales, chiefly in the Raritan valley, of the trap ridges which interrupt its continuity and of the enclosing highlands. To the

west is the Hunterdon escarpment, forming the westward limit of the Brunswick shales and marking the line of a great fault, by which the rocks of the plateau have been uplifted several thousand feet.[1]

Thirteen to sixteen miles to the north across the low shale plain are the gneiss highlands, and eight miles northeastward are the curving level crests of the Watchung trap ridges which are interbedded with the Brunswick shales, and beyond which the shale lowland extends. No high ground meets the eye to the east toward New Brunswick thirteen miles away, but to the south rises the Rocky Hill trap ridge, at one point deeply cut through by the Millstone, and there marking the approximate limit of the Brunswick shales. To the southwest there stretches away on either side of the narrow plateau on which we stand, a strip of rolling lowland, likewise underlain by the Brunswick shales.

These rocks also outcrop above the Lockatong series in the northern part of the Hunterdon plateau. They are exposed in high bluffs along the Delaware above and below Frenchtown. It was found that the shales of this area when traced along their strike towards the margin of the formation became rapidly coarser, passing along some horizons into massive conglomerates. It will be remembered that similar changes were found to take place in the Lockatong and Stockton beds, so that within two or three miles of the margin the distinctions between the three subdivisions are largely obliterated.

Quartzite conglomerates.—At a number of points along the northwestern boundary of the Newark system there are thick accumulations of massive conglomerates, composed chiefly of quartzite and hard sandstone. Pebbles of limestone, gneiss and shale occur in some layers, but sparingly. All the constituent

[1] The height of the plateau above the red shale plain is not due to the fault, although the latter lies along the foot of the escarpment. As shown by Professor Davis (Proc. Bost. Soc. of Nat. Hist., Vol. XXIV, pp. 365–423) this region was base-leveled in Cretaceous times or thereabouts, and the present topography is due to differential degradation of rock masses of unequal hardness, consequent upon an uplift which affected the whole region.

materials are well rounded, a fact which in the case of the hard quartzites indicates a long period of attrition.

These conglomerates interbedded with sandstones and shales are best exposed in the "pebble bluffs" along the Delaware, above Milford. The conglomerates form lenticular beds which occasionally thin out in the distance of a few rods, to be replaced by beds of different texture. The alternation of the beds betokens shore conditions.

The heaviest accumulations of the quartzite conglomerate underlie the high region stretching northwest from Pittstown and south of Pattenburg. This region is known as "the Barrens" from the nature of the soil, an exceedingly gravelly clay resulting from the disintegration of the conglomerate. Less massive accumulations occur, also, at other points, chiefly south of Clinton, and again four miles north of Peapack, where there is an outlier of this rock called Mount Paul.

Calcareous conglomerates.—Conglomerates composed almost entirely of limestone fragments, occur at a number of localities along this border. This rock is in appearance almost the exact counterpart of the famous "Potomac marble" quarried at Point of Rocks, Maryland. The limestone pebbles are usually bluish or gray, sometimes reddish, set in a red mud matrix, so that the rock has a variegated appearance. The average diameter of the larger constituents is six or eight inches, but bowlders three feet in diameter have been seen. The larger fragments are generally rounded, but the majority of the smaller are sharp cornered, or at most subangular. Compared with the pebbles in the quartzite conglomerate, the limestone pebbles are poorly rounded, a fact of some significance in connection with the origin and source of the materials, since with equal transportation, the softer limestones must have been most worn. In many localities this conglomerate is so pure a limestone that it is quarried and burnt for lime for local use.

The relations of these conglomerates to the older rocks along the border are significant. In some localities the calcareous conglomerates adjoin small areas of Palæozoic limestone from

which the materials may have been and probably were derived. In other cases, and this is true of the largest areas, the calcareous conglomerates abut against the gneissic rocks, and for much of this distance it is certain that no limestone occurs between the gneiss and conglomerate, at least not at the surface horizon. Gneissic pebbles, however, occur but rarely in the conglomerate. Substantially the same conditions prevail in the case of the quartzite conglomerate. For the most part it adjoins the gneiss, but gneissic pebbles in it are very rare. The known areas of quartzite from which the materials could have been derived are small, and in general not near the massive conglomerate beds. These facts can be explained on the hypothesis of a fault or series of faults along the northwestern border. But on the Delaware River, at Monroe, Pa., the only locality along the border where even an approach to a good section was found, the conglomerates seem rather to overlap the older rocks at a low angle, than to be faulted against them. In view of the contradictory nature of the evidence, the question of faults along this border is still an open one.

The relation of the conglomerates to the shales is also an interesting and significant one. When traced along the strike the shales and argillites are found to grade into coarser beds which at some horizons become the massive conglomerates near the border. That this is the case has been established beyond a shadow of a doubt by numerous observations. Time and again thin pebbly layers were seen to appear in the shales and to increase in thickness and numbers until they became massive conglomerates. This is true both of the calcareous and of the quartzite conglomerates.

These conglomerates do not, therefore, form a separate horizon but range through the whole formation. Those in the bluffs on the Delaware River above Milford belong with the Brunswick shales. So also do a part of those of the Barrens southwest of Pattenburg. Those of the Barrens north and northwest of Pittstown pass into the Lockatong beds and are therefore older than the conglomerates nearer the Delaware. The pebbly

beds south of Clinton belong in the Stockton series. Both the calcareous and quartzite conglomerates near Pottersville and Peapack belong with the Brunswick beds.

It must be understood that what has been said concerning the above conglomerates does not apply to the conglomerate layers interbedded with shales and sandstones, which occur either along the southeastern part of the formation, near Hopewell or near Stockton. The latter are comparatively thin beds of little importance from a topographical standpoint, and belong to the Stockton series. They present no features of particular interest.

Thickness of the Newark sedimentary beds.—All estimates of the thickness of these sedimentary rocks contain an element of uncertainty. This arises from the monotonous character of the beds and the difficulty of detecting and measuring the faults. In addition to several very large dislocations which have been located accurately, a number of smaller fractures have been observed in quarries, railroad cuts, stream bluffs, and other exposures. Most of these could not be traced beyond the point of exposure. After making all possible allowance for known faults, I am compelled to admit that the facts in hand indicate a vastly greater thickness than has usually been supposed.

The thickness of the Stockton beds between Trenton and Wilburtha seems to be 2300 feet. No estimates can be made in the area near Hopewell, since only the upper part of the series, 650 feet or so, is there exposed. At Brookville below Stockton the base of the formation is brought to the surface by a fault and the thickness seems to be 4700 feet. No positive evidence of a fault could be found within this area to account for the greater thickness as compared with the belt near Trenton, whereas there is slight evidence that the whole series is not found near the latter place.

The thickness of the Lockatong beds is best shown on Hunterdon plateau. Here the upper and lower limits can be carefully located. The dip is more than ordinarily uniform and outcrops are sufficiently numerous to prevent any great error in

the calculation. More than this, the sweeping curve of these rocks, the uniform width of the belt, and the possibility of tracing certain subordinate but well-marked layers continuously along the strike, precludes the idea that any great part of its apparent thickness is due to repetition by faulting. Three independent measurements, made at intervals several miles apart gave results of 3540 feet, 3450 feet, and 3500 feet respectively.

Three measurements of the thickness of these same beds in the Sourland plateau gave substantially the same results, *i. e.*, 3600 feet, 3650 feet, and 3660 feet. The fact that for a part of the distance a great trap sheet has been intruded into these beds and elsewhere has caused changes in the adjoining red shales, makes it a little more difficult to measure these beds. The fact that the thickness of these beds in Sourland plateau agrees so closely with that of the same beds on Hunterdon plateau is further reason for believing that the figures here given represent very closely the actual thickness. To suppose otherwise is to assume that these two separate areas are each traversed by faults, whose throw, by a remarkable coincidence, is almost exactly the same, but no traces of which have been discovered by areal work of the most detailed character.

The thickness of the Lockatong beds of the belt near Ewingville and Princeton seems to be only about half of that in the other two regions, *i. e.*, 1700 to 1800 feet. As noted above, the same relative thinness was observed in the Stockton beds near Trenton as compared with those further north. The explanation may lie in the fact that the beds of the thinner belts are nearer the old shore line than the others. Stratified deposits have the form of an unsymmetrical lens which thins out very rapidly shoreward and very gradually seaward. It is to be expected, therefore, that the thickness of this belt would be somewhat less than that of the others, but it may be fairly questioned whether in the case of such fine deposits the difference would be so great as that indicated by the figures.

The thickness of the Brunswick beds is even more difficult

to estimate accurately. This is due to the uniformity of the red shale, which renders it very difficult to detect the presence of faults, to the folded structure, and to the fact that the entire thickness is not present in this part of the state.

West of Ringoes the shales form a syncline whose axis plunges northwest. Estimates made here show that between 7000 and 8000 feet of shales are involved in this folding. Between the mouth of Lawrence Brook, east of New Brunswick, where the shales disappear beneath the Cretaceous cover, and the base of First mountain, back of Bound Brook, the beds are 10,000 feet thick, provided there are no faults in the intervening region. In the Raritan River bluffs below New Brunswick three fault breccias were found, but nothing is known as to the amount of dislocation beyond the fact that it was not sufficient to expose the Lockatong beds which are here at a horizon about 1000 feet lower. From the amount of disturbance and crushing which is known to accompany great faults in other parts of this area, the presumption is that these are small. A deduction of 1000 feet from the above estimate would seem to be ample for these and any undiscovered fractures. Nine thousand feet, however, is not enough, since neither the base nor the top of the Brunswick beds is included in this section. They certainly extend for 2000 to 3000 feet above the base of First Mountain. In the light of the present facts an estimated thickness of 12000 feet for the Brunswick shales does not appear excessive, although in view of the uncertainties connected with the structure, too much emphasis must not be placed upon it.

The total thickness, therefore, of the sedimentary rocks of the Newark system in western New Jersey seems to be about 20,000 feet. These figures are so great that one naturally hesitates to accept them, but the facts, so far as known, do not permit any other interpretation. I began my work feeling confident that the thickness of the beds was much less than this, and that they were many times repeated by faults. However, many of the faults found cross the beds at such angles as to be ineffective in repeating the strata. Furthermore, the fact that the

three estimates of the thickness of the Lockatong beds in the Hunterdon plateau, where the outcrop is so curved, agree closely one with another, and also with the various estimates of the same beds on Sourland plateau, make it improbable that the great thickness of this series is due to faults. So, too, the thickness of a *part* of the Brunswick shales involved in a synclinal fold can be accurately determined and the possibility of the faulting there eliminated. Again a narrow trap dike was traced uninterruptedly from the back of Sourland Mountain near Rocktown to Copper Hill, a distance of five miles. The dike crosses the strike at an angle of 45° and the thickness of the shales thus traversed is between 6000 and 7000 feet. There are reasons which cannot here be specified for concluding that the Sourland trap sheet, and therefore the dike, were intruded into the shales during Newark time, and before or contemporaneous with the tilting. If these reasons are valid the continuity of the dike is proof that the shales traversed by it are not cut by faults along the strike. Since such great thicknesses prevail in these beds, which are only a part of the whole system, there is the more reason for accepting the figures given above. It can certainly be claimed for these estimates that they rest upon a much larger basis of fact than any previous figures.

Trap rock.—The trap rocks in the Newark series have been described by various writers[1] who have shown that both intrusive and extrusive sheets occur. In this connection I desire briefly to call attention to a few new facts which confirm the conclusions of some of the earlier observers.

Three narrow dikes were found to start from the upper surface of the Sourland Mountain trap mass, and were traced through the overlying shales for several miles. Their existence proves conclusively that this sheet is intrusive. It would naturally follow that the continuation of Sourland Mountain in Pennsylvania is also intrusive, although Lyman[2] has published very positive views to the contrary. Moreover the fact that the trap

[1] Chiefly COOK, RUSSELL, DAVIS, DARTON, IDDINGS.

[2] Pennsylvania State Geol. Surv., Final Rept., Vol. III, Pt. II, p. 262.

locally cuts across shales for a total of 1800 feet is certainly well established. The Rocky Hill trap sheet does not follow the strike of the shales but crosses them more or less obliquely. Where it terminates near Hopewell it is 6000 feet[1] or more above the base of the Brunswick shales, whereas at Deans station where it disappears beneath the Cretaceous beds, it is 1500 feet below them. If we are correct in assuming that Rocky Hill is a continuation of the Palisades, the sheet descends still further, since along the Hudson it is found in beds which certainly belong to the Stockton series. A recently dug quarry opposite Point Pleasant, Pa., on the Delaware, shows that the trap mass there crosses the shales at a steep angle and is also intrusive.

Near Sand Brook village, southwest of Flemington, there is a low horseshoe-shaped ridge of trap formed by the outcropping edges of a synclinal sheet whose axis plunges northwestward. This sheet is extrusive in origin, as is shown by the following facts: (*a*) It is conformable to the enclosing shale; (*b*) the upper surface is everywhere extremely vesicular and only the lower portion is dense and full grained; (*c*) the overlying shale is absolutely unaltered within one and two feet of the trap; (*d*) red shale has filled some of the cavities of the vesicular trap, and in one locality a thin layer of finely comminuted trap, glass and red shale lies between the normal red shale and the vesicular trap. This sheet has not heretofore been described or shown upon published maps.

Metamorphosed shales.—Numerous allusions are made in the earlier reports to metamorphosed or "baked" shales associated with the trap and in some cases found far away from any igneous rocks. The black argillites of the Lockatong series have been called "baked shales" by some writers and their hardness and blackness ascribed to the contact with the trap, although no igneous rocks occur near them. Metamorphosed shales do occur in connection with the larger in usive trap masses, but all the

[1] These figures are correct just so far as the above given figures of the total thickness are reliable.

hard black shales are not "baked" shales. The most marked macroscopic changes induced in the altered shales are (*a*) a greater or less induration, (*b*) change in color,—the red shales in general becoming purple and then a blue-black or green near the trap, and (*c*) the development of secondary minerals,—very commonly epidote and tourmaline. Where the change has not produced definite crystal forms or nodules, an incipient segregation has often occurred, giving the rock a more or less mottled aspect, and on weathered surfaces a warty appearance, although this latter characteristic is not limited to the metamorphosed beds, but occurs in some layers of the Lockatong beds far from any known trap.

Of these three changes the third is believed to be the most significant. Mere induration or change of color do not necessarily signify "baking," but when all three occur together and only in layers in close proximity to certain trap sheets, proved to be intrusive by their structural relations, the changes can be safely ascribed to the igneous rock. Many of the baked shales, on weathering, become a pale blue or ashy gray color, a tinge never taken by other layers.

Metamorphosed shales occur both above and below the trap of Sourland Mountain and are well exposed in the bluffs near Lambertville. They are associated also with the Rocky Hill sheet, fine exposures being found along the canal near Rocky Hill village. In fact all the intrusive trap sheets are surrounded by shales which have been more or less altered in texture, color, and mineralogical constitution. Baked shales surely exist near some of the trap sheets, but all hard, black shales of the system are not baked, as was formerly supposed.

Unclassified beds.—It has been impossible to classify definitely the beds of a small area between Mount Airy, Lambertville, and the mouth of Alexsocken Creek. Their structure is complex, the dips vary greatly in direction and amount, and in many cases they are crushed and distorted. Two small masses of trap occur within the area, and some of the beds are certainly metamorphosed. Whether they belong to the Lockatong or Bruns-

wick division I am unable to say on account of the complexity of structure and their varied lithological character.

STRUCTURE.

Folds.—The general structure is that of a faulted monocline, the beds of which trend N. 30° E., and dip 12° or 15° to the northwestward. Examined in more detail the structure is seen to depart locally from the monocline. Several broad, gentle flexures occur, in addition to a few sharply marked folds in the vicinity of the intrusive traps and greater fault lines. A good example of the former is seen in the shales of the Hunterdon plateau, where the beds are so inclined that their outcropping edges describe a great curve parallel on the east and southeast to the escarpment of the plateau. The structure is a shallow syncline, whose axis is inclined to the northwest. Low folds were found along the valley of the Raritan, particularly in the region north of Somerville. From New Brunswick to Bound Brook the dip is quite uniformly to the northwestward, averaging 10°, but to the west the monocline is interrupted by gentle flexures and swells which are difficult to trace because of the absence of individuality in the layers. The broad outcrop of the Brunswick shales in the Raritan valley is due in large part to these low folds.

More definite folds—all synclines—occur (*a*) near the Sand Brook trap sheet southwest of Flemington, (*b*) the New Germantown trap sheet, and (*c*) the Watchung traps whose great crescent curves are due to the synclinal structure of the inclosing shales.[1] In consequence of this fold the beds which outcrop near the crystallines along Mine Brook, northeast of Bedminster are at the same horizon as those between the two trap sheets back of Plainfield and Bound Brook.

Several examples of sharp folds occur near Glen Moore southwest of Hopewell and not far from the end of Rocky Hill ridge. Other instances were noted near the faults.

The beds of the Stockton and Lockatong divisions are most

[1] COOK, DARTON, DAVIS, et al.

constant in dip and strike, so that the monoclinal structure is most marked in these belts. The Brunswick shales are marked by shallow folds, some covering an area of several square miles. These combined with a fortunate arrangement of faults, have greatly increased the area of red shale outcrop, and so permitted the formation of the broad, rolling lowland, so characteristic of the greater part of the Newark system.[2]

Faults.—The location of the most important faults by which these rocks are traversed is shown on the map. The Hopewell fault, heretofore unrecognized, extends in a sinuous course from near the Delaware River by Harbourtown, Hopewell, and thence along the foot of the Sourland plateau escarpment, passing a little west of Flagtown station on the Lehigh Valley Railroad. It probably crosses into Pennsylvania, but its exact location at the Delaware River could not be definitely determined.

The evidence of faulting along this line is as follows: (*a*) the repetition of the strata; (*b*) crushed and contorted shales, slickensided surfaces or overthrown dips at every exposure along or near the fault line; (*c*) diversity of structure, dip and strike—on opposite sides of the fault line; (*d*) contrasts in topography and the termination of ridges at the fracture. The repetition of the strata has already been alluded to in describing the rocks. The map shows how the Stockton, Lockatong and Brunswick beds are repeated, the beds to the northwest having been uplifted. In the bed of every stream crossing the fault, evidence of the fracture was found in the crushed and slickensided condition of the rocks, but the fault plane was nowhere exposed. Locally the rock has been so greatly sheared as to destroy all traces of the bedding planes. Very marked overthrown dips occur in a cut just west of Flagtown station, which increase in steepness towards the fracture. Folds in the Brunswick beds on the southeast side terminate abruptly against the fault and do not affect the beds on the opposite side. The high Sourland plateau composed of the hard trap and resistant

[2] The details of structure, which must be omitted here, are given in the Annual Report of the State Geologist of New Jersey for 1896, pp. 72–78.

Lockatong argillite terminates abruptly where the fault crosses the strike of its beds. The height and prominence of the escarpment north of Skillman station is due to the contrast in hardness of the Lockatong and Brunswick shales brought into juxtaposition by the fracture.

The dislocation has been sufficient to bring to the surface the upper part of the Stockton beds, and place them side by side with the middle layers of the Brunswick shales. On the basis of the above estimates of thickness the throw cannot be less than 10,000 feet. The hade of the fault cannot be determined, since the fracture is nowhere exposed in section and its location can rarely be determined within fifty yards. North of Flagtown, where the Brunswick shales occur on both sides of the fracture, its course could not be determined.

Flemington fault.—The course of this fault previously noted by other workers[1] is best seen by reference to the map. It is located in the bluffs of the Delaware River by the juxtaposition of the coarse arkose conglomerate (Stockton) with the black argillite (Lockatong) a mile or more south of Stockton. The line of dislocation is concealed by the talus of a small ravine. From this point it extends in a northeasterly direction for three miles, thence curving a little to the north so as to pass east of Headquarters, southeast of Sand Brook and a mile west of the center of Flemington. For much of this distance it extends along the foot of the Hunterdon plateau escarpment.[2] For several miles north of Flemington its exact location becomes doubtful owing to the similarity of the adjoining beds, but one or perhaps both of the two faults along the border west of Cushetunk Mountain mark its northern extension. There is some reason for believing that the trap of Round mountain, south of Cushetunk Mountain, has ascended along the fracture, but this is not conclusively proven.

The evidence of this fault is as complete as in the case of

[1] LEWIS, DARTON, NASON, LYMAN, and others.

[2] On a "conjectural" map of the Newark formation of New Jersey (Lyman, Pa., Geol. Surv. Summary Final Report, Vol. III, Pt. II, Plate 597, also Proc. Am.

the Hopewell fault. It consists of (*a*) repetition of the strata, (*b*) diversity of structure and topography on the two sides, (*c*) local disturbances, crushed beds, overthrown dips and slickensides.

The uplift was on the northwest and was sufficient to bring to the surface the base of the Stockton beds and just across the river in Pennsylvania, the Palæozoic floor on which the Newark beds rest. East of Headquarters and Sergeantsville, lower members of the Stockton series abut against beds of the Brunswick series apparently 2600 feet above the base. If we accept the thicknesses already given, the throw of the Flemington fault near Headquarters is not less than 10,000 feet.

Half a mile east of Sand Brook village a small fault splits off from the main fracture. By it a part of the Lockatong beds of the plateau have been downthrown so that they occur to the east, and apparently below the Stockton beds. The beds between the two faults are much confused in structure.

Another and larger split fault was observed to branch from the main fracture between Headquarters and Dilt's Corners. It crosses the Delaware about midway between Stockton and Lambertville, and from a cursory examination I am inclined to believe that it joins the Flemington fault again in Pennsylvania about a mile from the river. The rocks of this block belong to the Lockatong and Stockton series with some intrusive trap masses. The general dip is south of west, although near the faults there is much diversity. The beds on the east and southeast have been downthrown relatively to the others. The combined throw of this fault and the Flemington fault is about equal to that of the latter further north.

Faults of a few feet throw have been noted in not a few cases in quarries, railroad cuts and other exposures. In still other cases the amount of dislocation could not be determined, but they could not be traced beyond the point of exposure, and the throw

Philos. Soc., Vol. XXXIII, p. 194), the fault has been located several miles from its proper position. A similar error is found on the map in Proc. Am. Philos. Soc., XXXI, No. 142.

probably was not great. It is not believed that there are other faults in the area examined whose throw is even one-tenth that of the two great ones. I have alluded elsewhere to the possibility of faults along the northwestern border. Two are shown upon the map and others are believed to exist, but are not mapped. The recurving horn of the Second Watchung Mountain is quite certainly separated from the crystallines by a fault. Further investigation of these points together with the study of the region not yet examined, is now in progress.

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